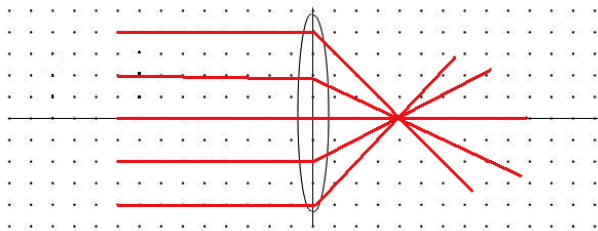


## Physics Laboratory: Lenses

We have already seen how Snell's Law describes the refraction of light as it passes through media with different indices of refraction. *Lenses* are made of materials that generally range in index of refraction from 1.5 – 1.8. Lenses are ground into specific shapes to control the refraction of light. In general, a lens that is wider in the middle than at the edges will cause light to converge. A lens that is narrower in the middle than at the edges will cause light to diverge. The lenses that will be studied in this course will have spherical surfaces and will be relatively thin. Lenses have a multitude of applications, from vision correction to cameras and projectors. The application determines the specific shape of lens that will be needed to do the job.

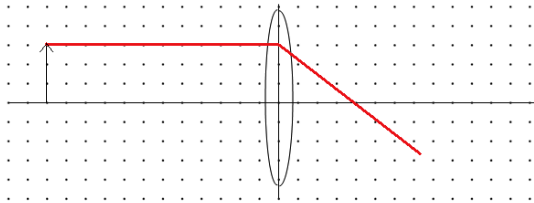
### I. Bi-Convex Lenses (sometimes just called convex lenses)

- a. A convex lens will converge parallel light rays to a point called the *focal point* of the lens.



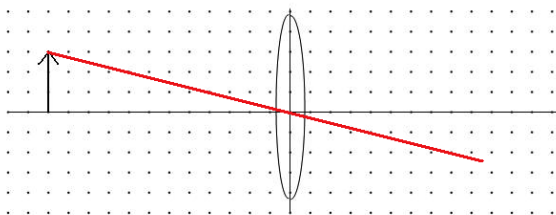
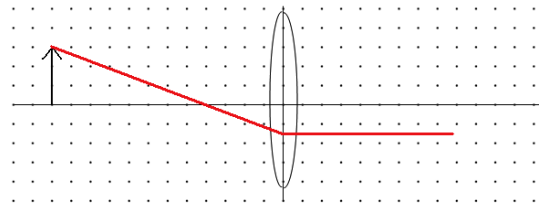
Try to create this with your ray box and convex lens cross section.  
What is the focal length of your lens?

- b. A convex lens forms images with different characteristics depending on where the object is located relative to the focal point of the lens.
- c. Ray tracing is used to predict the location and characteristics of images formed by lenses. For a convex lens, there are three principal rays:



**Parallel Ray:** A ray approaching the lens parallel to the principal axis will be refracted through the focal point.

**Focal Ray:** A ray approaching the lens through the focal point will be refracted parallel to the principal axis.



**Center Ray:** A ray that passes through the center of the lens will pass through without a change in direction.

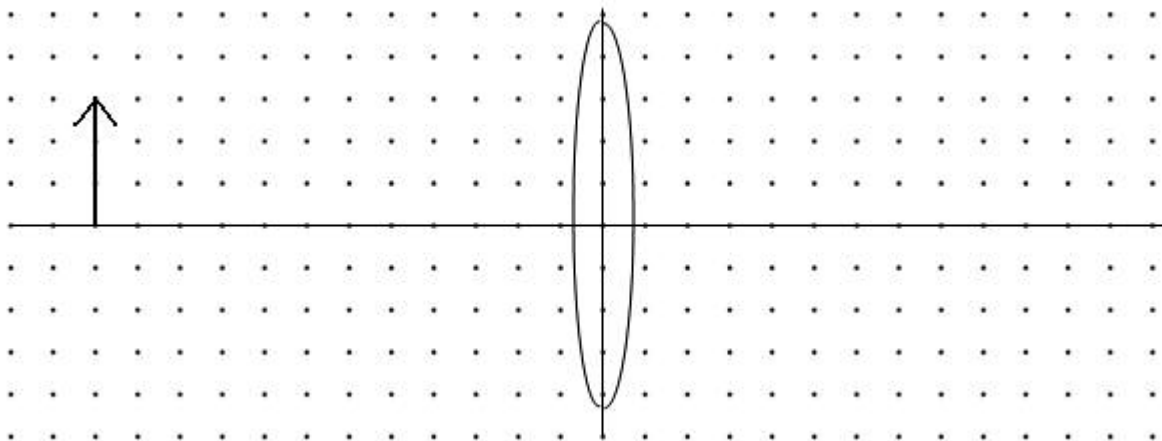
Create each of these rays using your lens and laser. Trace them on the grid paper.

Using these principal rays, five different classifications of images can be demonstrated.

II. Forming a real image with a convex lens. A real image is formed by the intersection of light rays.

- a. Case 1 – An object very far from a convex lens. An object is  $3F$  away from the lens. Draw the three principal rays to predict where the image will be located. Start each ray from the tip of the arrow. Use a ruler.

1. The image of the tip of the arrow is formed where the rays intersect. Since it is below the principal axis, the image of the arrow is upside down. Draw the image of the arrow.

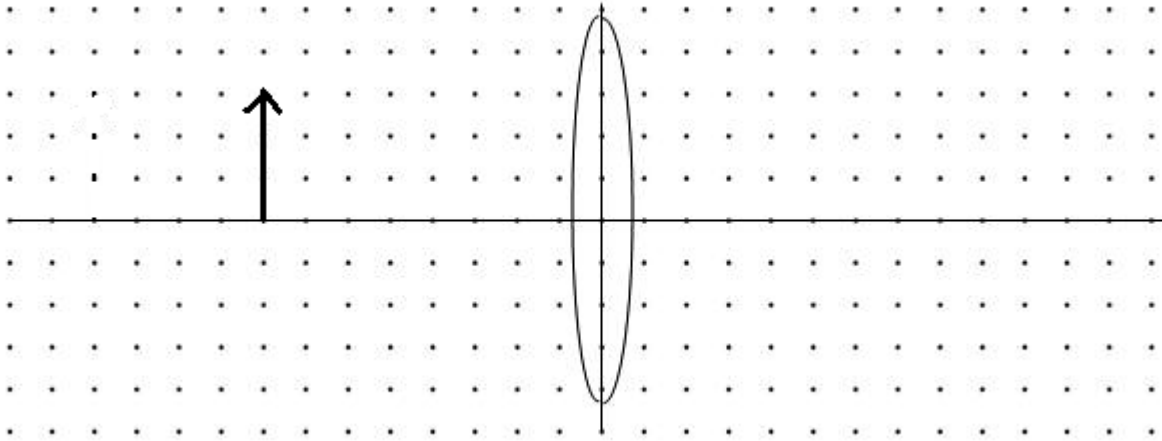


ii. Classify the image.

1. The rays intersect so the image is **real**.
  2. The image of the arrowhead is below the principal axis so the image is **inverted**.
  3. The image of the arrow is **smaller/larger** (circle one) than the original arrow.
- iii. The ray diagram is a scale diagram. It can be used to determine the position and size of the image. Estimate the image position and size.

- b. Case 2 – An object is two focal lengths from a convex lens. Draw the three principal rays to predict where the image will be located. Start each ray from the tip of the arrow. Use a ruler.

- i. The image of the tip of the arrow is formed where the rays intersect. Since it is below the principal axis, the image of the arrow is upside down. Draw the image of the arrow.



- ii. Classify the image.

1. Real/Virtual (circle one). Justify \_\_\_\_\_

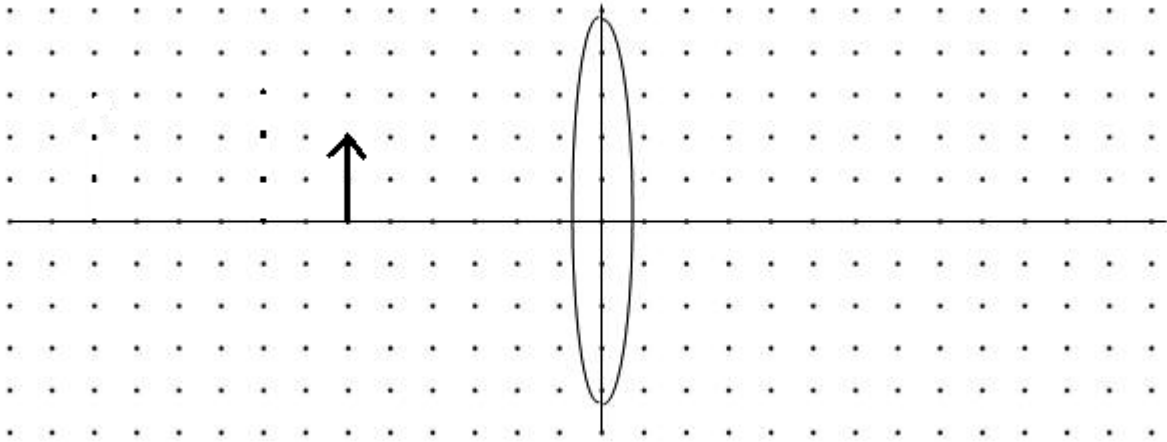
2. Upright/Inverted (circle one). Justify \_\_\_\_\_

3. Smaller/Larger. Justify. \_\_\_\_\_

- iii. Estimate the image position and size.

- iv. Magnification is image size divided by object size. Estimate the magnification of this image.

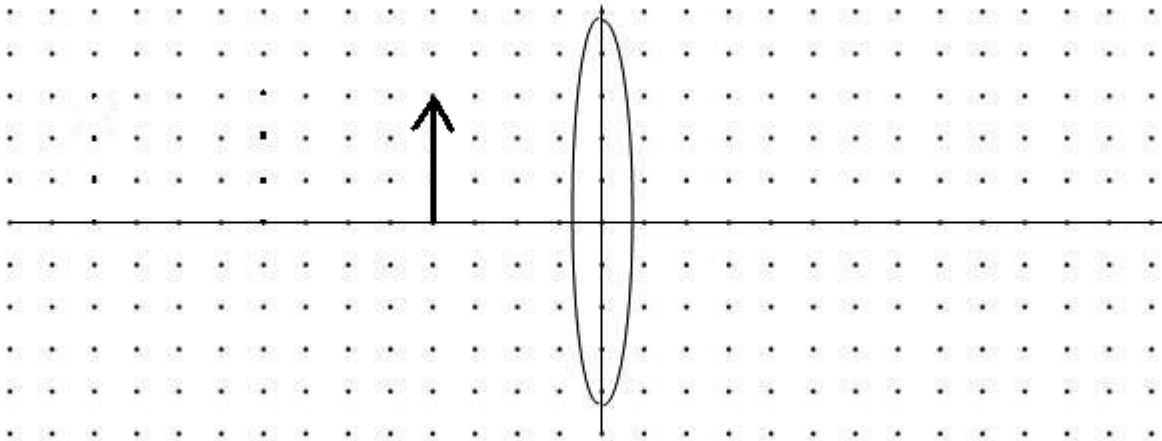
- c. Case 3 – An object is between one and two focal lengths from a convex lens. Assume a focal length of four dots. An object is 6 dots away from the lens. Draw the three principal rays to predict where the image will be located. Start each ray from the tip of the arrow. Use a ruler.



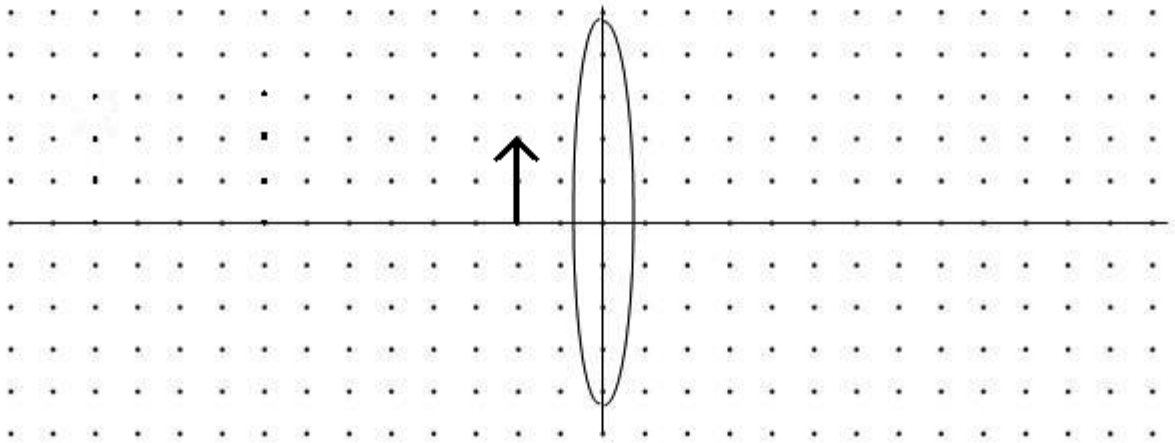
- i. The image of the tip of the arrow is formed where the rays intersect. Since it is below the principal axis, the image of the arrow is upside down. Draw the image of the arrow.
- ii. Classify the image.
  1. Real/Virtual (circle one). Justify \_\_\_\_\_
  2. Upright/Inverted (circle one). Justify \_\_\_\_\_
  3. Smaller/Larger. Justify. \_\_\_\_\_
- iii. Estimate the image position and size.
- iv. Magnification is image size divided by object size. Estimate the magnification of this image.

- d. Case 4 – An object exactly one focal lengths from a convex lens. Draw principal rays #1 and #3 to predict where the image will be located (#2 cannot be drawn for this case). Start each ray from the tip of the arrow. Use a ruler.

i. There is no image formed in this case. Why? \_\_\_\_\_



- e. Case 5 – An object is  $0.5F$  from a convex lens. Draw principal rays #1 and #3 to predict where the image will be located. Principal ray #2 can be drawn, but it is a bit tricky. To draw principal ray #2, line up your arrow with the focal point and the arrow tip. Draw a ray that travels as if it came from the focal point to the arrow tip and then to the lens. That ray will refract parallel to the principal axis. Use a ruler.



- i. A real image is formed when the rays intersect. In this case, the rays do not intersect. Your eye will see an image at the point where the two outgoing rays appear to come from behind the lens. Extend the outgoing rays back behind the lens, using dashed lines since the rays do not actually go there. Where the two dashed lines intersect, the virtual image is formed. Since it is above the principal axis, the image of the arrow is upright. Draw the image of the arrow.
- ii. Classify the image.

1. Real/Virtual (circle one). Justify \_\_\_\_\_

2. Upright/Inverted (circle one). Justify \_\_\_\_\_

3. Smaller/Larger. Justify. \_\_\_\_\_

iii. Estimate the image position and size.

iv. Magnification is image size divided by object size. Estimate the magnification of this image.

## Convex Lens Experiment

Materials: optical bench, convex lens, white paper screen, illuminated object.

### III. Observing the five cases of image formation with a real lens.

- a. Determine the focal length of your lens.
  - i. To find the focal point of your lens, use the lens to find the image of a distant object on a screen. The distance from the lens to the screen position where the sharpest image is obtained is your experimental focal point. Do this for three different distant objects.

|                                    | Trial 1 | Trial 2 | Trial 3 | Mean |
|------------------------------------|---------|---------|---------|------|
| Image Distance for far away object |         |         |         |      |

- ii. Record the image distance for each object. Compute the mean. You will use this for your experimental focal point.
- b. Set up each of the five cases outlined above. For each case, record object distance, image distance, object height and image height, magnification and image characteristics (upside down or upright, magnified or reduced, real or virtual). Make a table to record your measurements.

| Case | Obj. Dist. (m) | Measured Img. Dist. (m) | Obj. height (m) | Img. Height (m) | Mag. | Image Char. |
|------|----------------|-------------------------|-----------------|-----------------|------|-------------|
| 1    |                |                         |                 |                 |      |             |
| 2    |                |                         |                 |                 |      |             |
| 3    |                |                         |                 |                 |      |             |
| 4    |                |                         |                 |                 |      |             |
| 5    |                |                         |                 |                 |      |             |

For use later, you will need two additional data points. For two additional  $d_o$ 's for which real images will be obtained, record  $d_o$  and  $d_i$ .

Additional data point 1  $d_o =$  \_\_\_\_\_ ,  $d_i =$  \_\_\_\_\_

Additional data point 2  $d_o =$  \_\_\_\_\_ ,  $d_i =$  \_\_\_\_\_

c. How did your measurements compare to the predications of your ray tracing diagrams.

i. Case 1

ii. Case 2

iii. Case 3

iv. Case 4

v. Case 5

The lens equation,  $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$ , applies to both convex and concave lenses. By convention, signs are applied as follows:

| Quantity  | Positive when:              | Negative when:                             |
|---|-----------------------------|--|
| Focal length, $f$   | Converging lens (bi-convex) | Diverging lens (bi-concave)                |
| Image distance, $d_i$                                     | Real image                  | Virtual image                              |
| Object distance, $d_o$                                    | Real object                 | Virtual object<br>(only w/multiple lenses) |
| Magnification<br>$M = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$ | Image is upright            | Image is inverted                          |

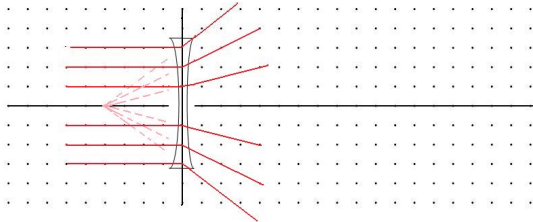
The results of calculations can also be used to predict image position and characteristics!



1. Use the lens equation to calculate the image distance for each of the cases in your data table.
2. Create a graph of  $1/d_i$  vs.  $1/d_o$ . How can this graph be used, along with its linear fit and the lens equation to determine the focal length of the lens? Sketch your graph and the equation of the best fit line below.

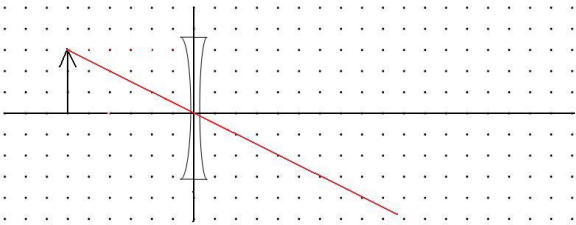
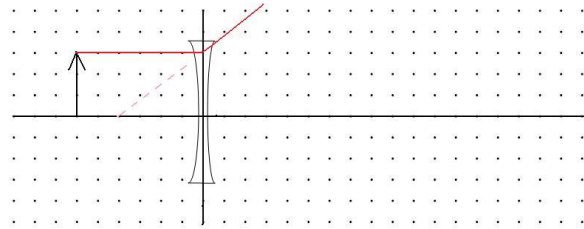
## Concave Lens

A concave lens diverges light as if the light were coming from one point. This point is the focal point for the concave lens.



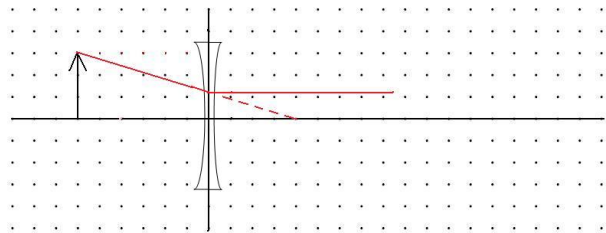
A concave lens has three principal rays:

**Parallel Ray:** A ray parallel to the principal axis is refracted as if it is coming from the focal point.



**Center Ray:** A ray that passes through the center does not change its path.

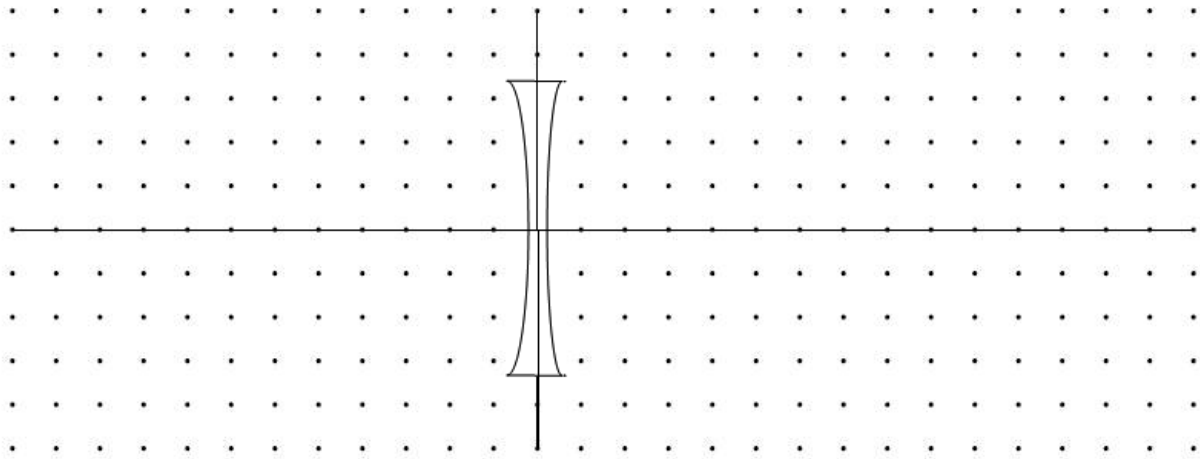
**Focal Ray:** A ray that is coming toward the focal point on the other side of the lens is refracted parallel to the principal axis.



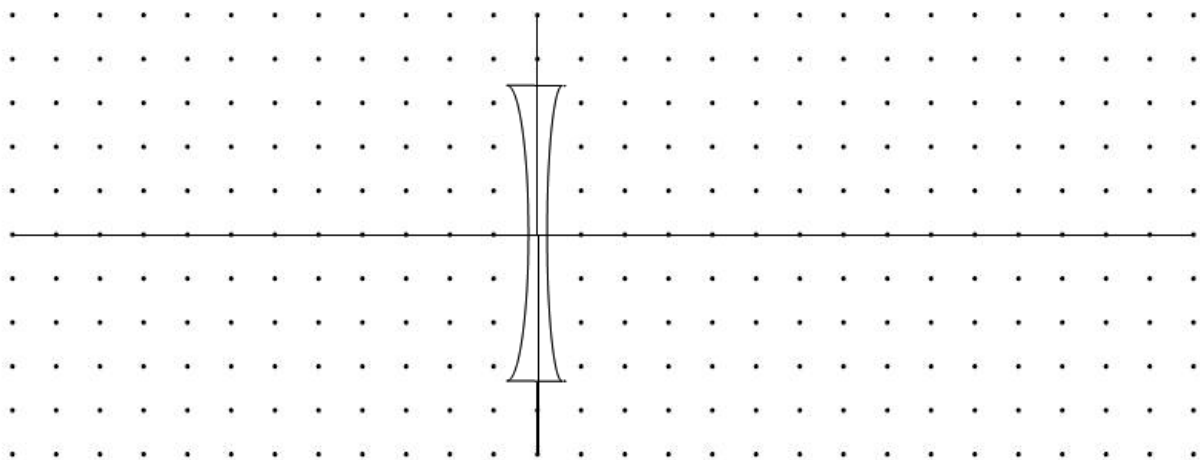
Try each of the principal rays with your laser and lens. Trace them on grid paper.

For the concave lens there is only one case for image formation. Where the object is relative to the focal point does not affect the characteristics of the image.

Locate the image of an object arrow using the three principal rays. Place the object further than the focal point.



Try another case. Place the object closer than the focal point. Does the image have the same characteristics?



Using the concave lens, observe the images formed for objects far away from the lens and close to the lens. Note: since all the images are virtual, you will not be able to see them using a screen, or measure image distance. Look at the object through the lens and note what you see. By estimated the height of the image, you can calculate the image distance using ratios.

| Case         | Object distance (m) | Object height (m) | Image height (m) | Magnification | Image distance $D_i = -M d_o$ (m) | Characteristics of Image (virtual/real, upright/inverted, magnified/reduced) |
|--------------|---------------------|-------------------|------------------|---------------|-----------------------------------|--|
| Far object   |                     |                   |                  |               |                                   |  |
| Close object |                     |                   |                  |               |                                   |  |

How are the image formation properties of lenses and mirrors similar? How are they different? Write a short essay. Describe at least three similarities and two differences.